SPECIFICATION

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[DEVICE AND METHOD FOR MONITORING FUEL CELL PERFORMANCE AND CONTROLLING A FUEL CELL SYSTEM]

Cross Reference to Related Applications

This application is based on applicant's provisional application 60/231,943 filed on September 12, 2000.

Background of Invention

[0001] The present invention relates to a device to measure individual or grouped cell voltages to monitor fuel cell performance for diagnostic or control purposes. More particularly, the present invention involves a device to make attachments to individual cells or groups of cells of a fuel cell stack which measures the voltage of these individual cells or groups of cells and uses these measurements, the change in these measurements, or the time response of these measurements to report on the performance of the fuel cell stack and to control fuel cell system parameters or isolate poorly performing cell groups based on this performance data. The present invention also provides a method to measure a plurality of voltages at a plurality of points around the perimeter of cells or cell groups to realize a non-invasion measurement of disproportionate current density distribution across the surface of these cells. The present invention further extends to an associated device in communication with the said measuring device to modulate fuel cell stack current to allow dynamic performance measurements of individual or grouped cells.

[0002] Generally speaking a fuel cell is a device that uses an electrochemical process to generate electrical power utilizing the reaction of hydrogen and oxygen. A typical fuel cell is comprised of a multitude of individual fuel cells electrically connected in series to provided a practical voltage output, a voltage equal to the sum of all the individual fuel cells. This arrangement of a multitude of individual cells is referred to as a "fuel cell stack" and each individual cell a "cell." A fuel cell stack typically consists of 10 to 100 cells to realize a total output voltage that is practical for use as an electrical power generation device.

[0003] A typical fuel cell system can comprise a fuel cell stack, control or regulating devices for either or both of the reactant fluids (oxygen or air and hydrogen), control or regulating devices for humidification of either or both of the reactant fluids (oxygen or air and hydrogen), control or regulating devices for the cooling fluids (water or air), and a electronic controller to monitor fuel cell stack parameters and adjust control and regulating parameters accordingly.

[0004] Since the output voltage of the fuel cell stack equals the sum of all of the individual cells electrically connected in series, the overall performance of the fuel cell stack is an average of the performance of each individual cell. Furthermore, since all these individual cells are electrically connected in series a failure of one individual cell could possibly compromise the performance of the entire fuel cell stack. Therefore to insure the overall performance of the fuel cell stack it is important to monitor the performance of individual cells or groups of cells.

[0005] Additionally it is desirable to measure any variation in current density across the plane of cells. A disproportionate current density distribution will manifest itself as differences in cell voltage as measured at different points around the perimeter of a cell. The present invention can allow for voltage measurements to be made at two or more points of the outside perimeter and interpreting these voltage differences and displaying such in a manner to provide an effective determination of a disproportionate current density and hence an operational problem.

[0006] It is common for existing control devices to monitor fuel cell stack

performance based on the sum of all the cells, but since this voltage is much greater than that of individual cells and the cell voltages have some degree of uncertainty it is impossible to monitor the performance of individual cells and determine performance degradations of individual cells.

[0007] It is also desirable for the control system to isolate individual cells or cell groups that are performing poorly and whose performance has not been corrected by control means.

[0008] Accordingly, what is needed is a new and useful device and method for measuring individual or grouped cell voltages to monitor fuel cell stack performance for diagnostic or control purposes.

[0009] The prior art includes U.S. Patent 6,281,684 to James which is directed to a method and apparatus for measuring cell voltages of a fuel cell stack using different ground references. The apparatus includes scanning units coupled to a fuel cell stack to measure and indicate a voltage of each selected fuel cell in response to a selection signal.

[0010] U.S. Patent 6,281,684 to James also discloses a method for measuring cell voltages of a fuel cell stack which similarly includes scanning units coupled to a fuel cell stack.

[0011] U.S. Patent 5,170,124 to Blair discloses a method and apparatus for the measurement and comparison of fuel cell performance indicators, such as voltage, in groups of cells connected in series.

[0012] The citation of any reference herein should not be construed as an admission that such reference is available as "Prior Art" to the instant application.

Summary of Invention

[0013] There is provided, in accordance with the present invention, a new, useful, and unobvious device for measuring individual or grouped cell voltages to monitor fuel cell performance for diagnostic or control purposes. Such a device allows performance data to be collected on each individual cell or on groups of cells of

the fuel cell stack for stack performance analysis and fuel cell system control.

[0014] Broadly, the present invention extends to a device for measuring individual or grouped cell voltages to monitor fuel cell performance for diagnostic or control purposes, wherein the device comprises a contact arrangement which is associated with the fuel cell stack, which makes electrical connections to individual cells of the fuel cell stack and measures the voltages of said individual cells or cell groups. A device of the invention also comprises a monitor and/or controller, which uses these measurements to report on the performance of the fuel cell stack and to control fuel cell system parameters, based on this performance data.

[0015] The present invention further extends to an associated device in communication with the said measuring device and in electrical connection with the said fuel cell stack to modulate fuel cell stack current to allow dynamic performance measurements of individual or grouped cells, such as current voltage relationships, voltage transient response, and voltage frequency response.

[0016] The present invention further extends to performing said measurements at a multitude of points around the perimeter of individual cells or cell groups. Thus providing a non-invasive method to determine a disproportionate current density distribution across the plane of an individual cell or cell group.

[0017] The present invention further extends to associated apparatus in communication with the said measuring device and in electrical connection with individual cells or cell groups in that the said measuring device can instruct said associated apparatus to electrically isolate individual cells or cell groups which could compromise the performance of the entire fuel cell stack.

[0018] The present invention finds application in numerous types of fuel cells including, but certainly not limited to PEM (proton exchange membrane), Phosphoric Acid, and Molten Carbonate.

[0019] The present invention also finds application in numerous applications of fuel cells including, but certainly not limited to vehicular power, residential cogeneration, power generation, UPS (uninterruptible power supply), backup

power, battery replacement, battery charging, and portable power.

[0020] These and other objects of the present invention will be better appreciated and understood by those skilled in the art by reference to the following drawings and Detailed Description.

Brief Description of Drawings

[0021] FIG. 1 is a block diagram of a monitoring arrangement according to the present invention.

[0022] FIG. 2 is a block diagram of a monitoring arrangement including a personal computer as a monitor.

[0023] FIG. 3 is a block diagram of a monitoring arrangement including a current load according to one embodiment of the invention.

[0024] FIG. 4 includes side and top views of a spring contact cell contact arrangement.

[0025] FIG. 5 includes side and top views of an elastomer contact cell contact arrangement.

[0026] FIG. 6 includes side and top views of a cylindrical spring contact cell contact arrangement.

[0027] FIG. 7 is a block diagram of a meter according to the present invention.

[0028] FIG. 8 is a schematic view of a multiplexor.

[0029] FIG. 9 is an I V curve of the voltage to current relationship of an individual cell or cell group.

[0030] FIG. 10 is a Thevenin equivalency model of an individual cell or cell group.

[0031] FIG. 11 is voltage transient response curve of an individual cell or cell group.

[0032] FIG. 12 is a Thevenin equivalency model of an individual cell or cell group.

[0033] FIG. 13 is a switching apparatus connected to cell groups.

Detailed Description

[0034] The present invention involves a device to measure individual or grouped cell voltages to monitor fuel cell performance for diagnostic or control purposes. More particularly, the present invention involves a device to make attachments to individual cells or groups of cells of a fuel cell stack which measures the voltage of these individual cells or groups of cells and uses these measurements to report on the performance of the fuel cell stack and to control fuel cell system parameters based on this performance data. Consequently, an apparatus of the invention is new, useful and unobvious in light of heretofore known devices. Many other variations and modifications of a device of the invention will apparent to those skilled in the art without departing from the spirit and scope of the invention. The above-described embodiments are therefore, included to be merely exemplary, and all such variations and modifications are intended to be included within the scope of the invention as defined in the appended Claims.

[0035] As explained above, FIG. 1 is a block diagram of a monitoring arrangement according to the present invention. The monitoring arrangement shown in FIG. 1 includes a fuel cell stack (10), a cell contact assembly (11), a multiple conductor electrical signal path (12) from the cell contact assembly to a meter (13), an electrical signal path (14) from the meter to a monitor (15).

[0036] Referring again to FIG. 1, contact assembly (11) is associated with fuel cell stack (10). In a device of the present invention, contact assembly (11) associated with fuel cell stack (10) can be embedded in fuel cell stack (10), or mounted on fuel cell stack(10). Contact assembly (11) makes electrical connections with conductive areas of cells of fuel cell stack (10). Numerous mounting and positioning methods have applications in a device of the present invention. Particular examples of such methods include, but certainly are not limited to printed circuit boards, and machined bracket assemblies.

[0037]

Still referring to FIG. 1, contact assembly (11) is connected to meter (13) by means of a multiple conductor signal path (12) with at least one electrical path per cell or cell group. Numerous examples of such multiple conductor signal paths

include, but certainly are not limited to ribbon cable, individual wires, and flexible circuit boards.

[0038] Meter (13) measures voltages of individual cells or cell groups and communicates said voltage measurements or performance data via electrical signal path (14) to monitor (15). Monitor (15) provides a display method to provide a user with performance data of fuel cell stack (10). Numerous examples of such display methods include, but certainly are not limited to LED (light emitting diode) displays, LCD (liquid crystal displays), and VFD (vacuum fluorescent displays).

[0039] As an alternate monitoring arrangement, FIG. 2 is a block diagram of a monitoring arrangement according to the present invention that includes a personal computer (25) used as a monitor. The monitoring arrangement shown in FIG. 1 includes a fuel cell stack (20), a cell contact assembly (21), a multiple conductor electrical signal path (22) from the cell contact assembly to a meter (23), an electrical signal path (24) from the meter to a personal computer (25).

[0040] Referring again to FIG. 2, contact assembly (21) is associated with fuel cell stack (20). In a device of the present invention, contact assembly (21) associated with fuel cell stack (20) can be embedded in fuel cell stack (20), or mounted on fuel cell stack(20). Contact assembly (21) makes electrical connections with conductive areas of cells of fuel cell stack (20). Numerous mounting and positioning methods have applications in a device of the present invention. Particular examples of such methods include, but certainly are not limited to printed circuit boards, and machined bracket assemblies.

[0041] Still referring to FIG. 2, contact assembly (21) is connected to meter (23) by means of a multiple conductor signal path (22) with at least one electrical path per cell or cell group. Numerous examples of such multiple conductor signal paths include, but certainly are not limited to ribbon cable, individual wires, and flexible circuit boards.

[0042]

Meter (23) measures voltages of individual cells or cell groups and communicates said voltage measurements or performance data via electrical signal

path (24) to personal computer (25). Personal computer (25) provides a display method to provide a user with performance data of fuel cell stack (20). Numerous examples of such display methods include, but certainly are not limited to desktop computers, laptop computers, notebook computers, and PDA (personal digital assistant) devices. Software run on the personal computer (25) provides a presentation of the performance of individual cells, cell groups, or the entire fuel cell stack (20). The software run on the personal computer is developed using routine programming techniques readily available to one of ordinary skill in the art.

[0043] As explained above, FIG. 3 is a block diagram of a monitoring arrangement according to the present invention further extended to include a current load (3). The monitoring arrangement shown in FIG. 3 includes a fuel cell stack (4), a current load (3) connected between current paths (1,2), a current load signal path (7), a cell contact assembly (5), a multiple conductor electrical signal path (6) from the cell contact assembly to a meter (8), an electrical signal path (9) from the meter to a monitor (10).

[0044] Referring again to FIG. 3, current load (3) is instructed by meter (8) to modulate current of fuel cell stack (4) through current paths (1,2). Numerous examples of such a current load include, but certainly are not limited to one or more bipolar transistors, IGBT"s (insulated gate bipolar transistor), MOSFET"s (metal oxide silicon field effect transistor), solid state relays, electronic loads, galvanostats, potentiostats, amplifiers, and mechanical relays.

[0045] Still referring to FIG. 3, voltage change, transient or frequency response of individual cells or cell groups of fuel cell stack (4) are measured by meter (8) through multiple conductor signal path (6) and contact assembly (5). Voltage change, transient or frequency response measured by meter (8) or performance data calculated is communicated through electrical signal path (9) to monitor (10).

[0046] FIG. 4 shows one embodiment of a contact module. Flexible electrically conductive contacts (10) of electrical connectors (11) make electrical contact with conductive exposed area of fuel cells. Electrical connectors (11) are supported by and properly spaced on a printed circuit board (12) which makes electrically

conductive signal paths to cable connector (13).

[0047] FIG. 5 shows another embodiment of a contact module. A flexible and compressible elastomeric strip (20) provides an electrically conductive signal path between the conductive exposed area of fuel cells and conductive traces (21).

[0048] FIG. 6 shows another embodiment of a contact module. Movable electrically conductive contact pins (31) supported by spring loaded bodies (30) make electrical contact with conductive exposed area of fuel cells.

[0049] As explained above, FIG. 7 is a block diagram of a meter according to the present invention. Electrical signals of the individual or grouped cells (1) are input to multiplexor (2). Microprocessor (7) instructs multiplexor (2) via multiplexor control signal (12) to select one of electrical signals of the individual or grouped cells which appears as multiplexor output signal (3). Microprocessor instructs attenuator (4) via attenuator control signal to attenuate or lessen multiplexor output signal (3) to provide amplifier (5) with proper signal voltage range. Converter (6) converts analog voltage signal from amplifier (5) to a digital voltage signal read by microprocessor (7). Microprocessor analyzes and interprets digital voltage signal to determine performance data and instructs communication interface (8) to communicate said performance data to monitor via monitor communication port (9). Microprocessor determines if said performance meets alarm criteria and if alarm criteria is met activates alarm output (10) to communicate alarm status to an external device via alarm communication port (11).

[0050] Numerous examples of microprocessors include, but certainly are not limited to 8 bit microcontrollers, 16 bit microcontrollers, 8 bit microprocessors, 16 bit microprocessors, DSP"s (digital signal processor), ASIC"s (application specific integrated circuit), FPGA"s (field programmable gate array). Moreover, a microprocessor can be readily programmed to read digital data from converter (6) and analyze and interpret said data to determine performance data using routine programming procedures known to the skilled artisan.

[0051] An example of an attenuator would include a voltage divider comprised of two resistors in which the amount of attenuation is controlled by the ratio of values of said two resistors.

[0052] Numerous examples of amplifiers include, but certainly are not limited to operational amplifiers, instrumentation amplifiers, and voltage buffers.

[0053] Numerous examples of converters include, but certainly are not limited to 8 bit A/D"s (analog/digital), 12 bit A/D"s, 16 bit A/D"s, 24 bit A/D"s, delta-sigma converters, dual slope converters, integrating converters, VCO"s (voltage controlled oscillator), VFC"s (voltage to frequency converter), modulators, sampling converters, flash converters, and successive approximation converters.

[0054] Numerous examples of communication interfaces include, but certainly are not limited to RS-485, RS-422, RS-232, USB (universal serial bus), CAN (control area network), PWM (pulse width modulation), and PFM (pulse frequency modulation).

[0055] Numerous examples of alarm outputs include, but certainly are not limited to mechanical relays, solid state relays, transistors, and optoisolators.

[0056] FIG. 8 shows one embodiment of a multiplexor. Two switches (1) in association with and electrical connection to individual cell or grouped cell voltage signals (2) provide an electrical signal path to multiplexor output (3). Numerous examples of switches include, but certainly are not limited to mechanical relay contacts, solid state relay contacts, MOSFET "s (metal oxide silicon field effect transistor), bipolar transistors, optoisolators, optocouplers, reed switches, and rotary mechanical contactors.

[0057] FIG. 9 shows one embodiment of an IV curve. A curve (10) represents the relationship of voltage of a individual cell or cell group to fuel cell stack current. Nonlinearities of this curve (10) are due to the combination of electrical characteristics, electrochemical processes, and physical processes. In a low current region (11) an electrochemical process is the majority contributor to curve (10). In a mid current region (12) an electrical characteristic is the majority contributor to curve (10). In a high current region (13) a physical process is the majority

contributor to curve (10).

[0058] FIG. 10 shows one embodiment of a Thevenin equivalency model of an individual cell or cell group. A voltage source (20) represents the open circuit voltage present at output terminal (24) when the fuel cell stack current is equal to zero. Ohmic resistance (21) represents the resistance due to electrical characteristics. Electrochemical process resistance (22) represents the resistance due to electrochemical processes. Physical process resistance (23) represents the resistance due to physical processes.

[0059] FIG. 11 shows one embodiment of a voltage transient response curve of an individual cell or cell group. A curve (10) represents the voltage of individual cells or cell groups as a function of time. Curve (10) starts at a steady voltage, $t < 0$, (11) before fuel cell stack current change time (14). At fuel cell stack current change time (14) curve (10) immediately approaches voltage, $t = 0$, (12). This voltage change in fast voltage change region (16) is due to electrical characteristics. In the slow voltage change region (17) curve (10) eventually approaches a low or zero current voltage (13) at time (15). The voltage change in slow voltage change region (17) is due to electrochemical and physical processes.

[0060] FIG. 12 shows one embodiment of a Thevenin equivalency model of an individual cell or cell group. A voltage source (20) represents the open circuit voltage present at output terminal (26) when the fuel cell stack current is equal to zero. Ohmic resistance (21) represents the resistance due to electrical characteristics. Electrochemical process resistance (22) represents the resistance due to electrochemical processes. Electrochemical process capacitance (23) represents the time constant due to the electrochemical process. Physical process resistance (24) represents the resistance due to physical processes. Physical process capacitance (25) represents the time constant due to physical processes.

[0061] FIG. 13 shows one embodiment of a switching apparatus connected to cell groups. A plurality of individual cells (1) of fuel cell stack (2) are in electrical connection with current plates (3) connected to electrical switches (4) so that one or more cell groups can be removed and isolated from the remaining fuel cell

groups of the fuel cell stack (2) whose current passes through connections (5,6). One or more switches under instruction of said measuring device can switch to isolate said individual cells or cell groups to isolate cell group and provide bypass current path. If said measuring device determines that an individual cells or cell groups are performing poorly or have been permanently damaged it can instruct said switching apparatus to isolate said individual cells or cell groups so as to not adversely affect entire fuel cell stack performance.

[0062] Numerous examples of such switches include, but certainly are not limited to bipolar transistors, IGBT"s (insulated gate bipolar transistor), MOSFET"s (metal oxide silicon field effect transistor), solid state relays, and mechanical relays.

[0063] Many other variations and modifications of a device of the invention will apparent to those skilled in the art without departing from the spirit and scope of the invention. The above-described embodiments are therefore, included to be merely exemplary, and all such variations and modifications are intended to be included within the scope of the invention as defined in the appended Claims